S28-90

N91-14128

p. 3

CS J= 2 → 1 Emission Toward the Central Region of M82

C. E. Walker (Steward Obs.), C. K. Walker (Caltech), J. E. Carlstrom (U.C. Berkeley), and R. N. Martin (Steward Obs.)

M82 is an irregular (Type II) galaxy located at a distance of approximately 3.5 Mpc. Its unusual appearance and high luminosity, particularly in the infrared, has led many astronomers to classify it as a starburst galaxy. This interpretation is supported by the observation of a large number of radio continuum sources within the central arcminute of the galaxy. These sources are thought to be associated with supernova remnants (Kronberg *et al.* 1985). The starburst in the central region of the galaxy is believed to have been triggered by tidal interaction with either M81 or the H I cloud surrounding the M81 group.

High angular resolution ^{12}CO J= 1 → 0 maps by Nakai (1984) and Lo *et al.* (1987) indicate the existence of a 400-450 pc rotating ring of molecular material about the central region of M82. Red- and blue-shifted absorption components of the H I and OH lines measured by Weliachew *et al.* (1984) provided the first evidence for the presence of the ring. Many astronomers, each using a different angular resolution, have compared ^{12}CO J= 1 → 0, J= 2 → 1, and J= 3 → 2 emission and concluded that a large fraction of the CO emission is optically thin (Knapp *et al.* 1980; Sutton *et al.* 1983; Olofsson and Rybeck 1984; Turner *et al.* 1989). Additional observations suggest that the molecular material toward the center of M82 is clumpy and dense (Loiseau *et al.* 1988 and Carlstrom 1988).

Unlike the lower rotational transitions of CO, CS is excited only at relatively high densities, $n_{H_2} \geq 10^4\,\mathrm{cm}^{-3}$. It is in clouds with these densities that stars are expected to form. This makes CS an excellent probe of star formation regions. We have observed the CS J= 2 → 1 transition (97.981 GHz) toward 52 positions in M82 using the NRAO 12 m telescope. The beamsize was ≈ 63″ and the spacing between observed positions was 20″. The spectral resolution was 6.1 km/s. An rms noise level of 4 mK per channel was obtained. CS was detected over a 160″ square region roughly centered on the 2 μm peak (0,0 offset). The emission is extended along the major axis of the galaxy. The map of the CS integrated intensity is shown in Figure 1.

The velocity centroid of each observed spectrum was computed. The observed velocity gradient closely resembles that observed in CO J= 1 → 0, (Young and Scoville 1984) and appears to be dominated by rotation about the minor axis of the galaxy. The similarity between the two velocity maps suggests that the CS and CO emission are arising from molecular clouds located at similar positions in the galaxy.

Estimates of the molecular column density along the lines of sight that CS J= 2 → 1 was detected can be made if we assume the emission is optically thin. By adopting an excitation temperature of 40 K and $\tau < 1$, we can estimate the CS column density across our beam. In this type of derivation the molecular column density toward a given position is proportional to the CS integrated intensity observed there. The peak column density is $3 \times 10^{13}\,\mathrm{cm}^{-2}$ and occurs ≈ 20″ east of the central position. For a fractional CS/H_2 abundance of 10^{-9} (Graedel *et al.* 1982), the corresponding H_2 column density is $3 \times 10^{22}\,\mathrm{cm}^{-2}$.

n sub H sub 2 ... equal to 10 (exp 4) cm(-3)

As mentioned earlier, the presence of CS emission indicates the presence of gas with a density $\geq 10^4\,\mathrm{cm}^{-3}$. If such high density gas uniformly fills the region over which CS was detected, then this implies a gas mass of $\approx 2\times10^{12}\,\mathrm{M}_\odot$. The dynamical mass of the region is only $\approx 4\times10^9\,\mathrm{M}_\odot$ (Young and Scoville 1984). The difference between the two mass estimates indicates that the dense gas is clumpy, with a filling factor $\leq 2\times10^{-3}$.

In Figure 2 we present a surface plot which shows the variation in the CO to CS integrated intensity ratio over the central region of M82. The CO data is from Young and Scoville ($\approx 50''$ resolution). The 0,0 position in Figure 2 is $\approx 15''$ west of the $2\,\mu$m peak. Along the major axis the I_{CO}/I_{CS} ratio peaks near the center and the edges of the map and has minima about $50''$ east and $30''$ west. In contrast, the I_{CO}/I_{CS} ratio reaches its lowest values at the edges of the map along a position angle close to that of the minor axis. Since the characteristic density of CO is much less than that of CS, lower values of I_{CO}/I_{CS} may indicate that a higher percentage of the gas is in dense clouds. The minima in Figure 2 are at the outer boundary of the dense molecular ring observed both in high resolution single dish (Nakai *et al* 1987; Loiseau *et al.* 1988) and interferometer (Carlstrom 1988) maps. Therefore, if a low value of the I_{CO}/I_{CS} ratio does indicate a large percentage of dense gas, then Figure 2 shows *there is a reservoir of dense gas located just outside the molecular ring found.* The peak I_{CO}/I_{CS} ratio at the map center would then suggest that although the largest column density of dense gas occurs toward the center (see Figure 1), the percentage of molecular gas in dense clouds within our beam is lower there than in the surrounding region.

The variation in the I_{CO}/I_{CS} ratio in Figure 2 could in principle be due to a variation of the CS fractional abundance across the source, perhaps due to shocks. However, model calculations by Hartquist *et al.* (1980) indicate that sulfur bearing molecules could be overabundant in shocked regions. Since the central region has a peak in the I_{CO}/I_{CS} ratio and is probably the most heavily shocked, it is unlikely that shock chemistry is significantly effecting the fractional abundance of CS.

A drop in the I_{CO}/I_{CS} ratio from a central peak could also occur if the gas temperature dropped as a function of distance from the center. In this situation the opacity in the CO J$=1\rightarrow0$ and the CS J$=2\rightarrow1$ lines would increase and may eventually saturate at larger radii. However, the more density sensitive CS would feel the effects of the decreasing temperatures more slowly than CO. The I_{CO}/I_{CS} ratio would decrease at increasing radii and eventually level off. However, this is not what is observed. Inspection of Figure 2 shows that the I_{CO}/I_{CS} ratio goes through a minimum and then sharply increases again along the major axis in both directions from the nucleus.

Different spatial resolution of CO and CS observations combined with a brightness gradient may also produce variations in I_{CO}/I_{CS}. We are currently investigating the effect of the ≈ 30 % difference between the NRAO and FCRAO beamwidths.

REFERENCES

Carlstrom 1988, *Galactic and Extragalactic Star Formation*, ed. Pudritz and Fich, Dordrecht: Reidel.
Graedel, Langer and Frerking 1982, *Ap. J. Supp.*, **48**, 321.
Hartquist, Oppenheimer and Dalgarno 1980, *Ap. J.*, **236**, 182.
Knapp *et al.* 1980, *Ap. J.*, **240**, 60.
Kronberg, Biermann and Schwab 1985, *Ap. J.*, **291**, 693.
Lo *et al.* 1987, *Ap. J.*, **312**, 574.
Loiseau *et al.* 1988, *Astron. Astrophys.*, **200**, L1.
Nakai 1984, *Ph.D. thesis*, University of Tokyo, Japan.
Nakai *et al.* 1987, *P. A. S. J.*, **39**, 685.
Olofsson and Rydbeck 1984, *Astron. Astrophys.*, **136**, 17.
Sutton, Masson and Phillips 1983, *Ap. J.*, **275**, L49.
Turner, Martin and Ho 1989, *Ap. J.*, submitted.
Weliachew, Fomalont and Greisen 1984, *Astron. Astrophys.*, **137**, 335.
Young and Scoville 1984, *Ap. J.*, **287**, 153.

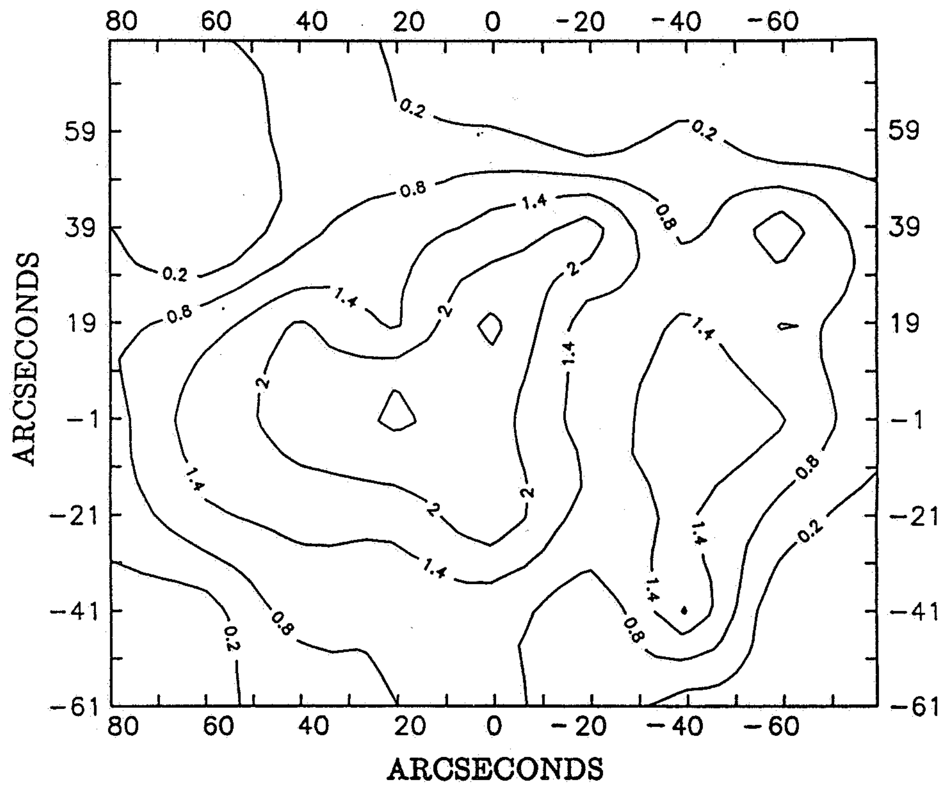

Figure 1 The CS J= 2 → 1 integrated intensity map of M82. The minimum contour level is 0.2 K km/s and the contour interval is 0.6 K km/s. The rms noise level is ≈0.06 K km/s. The 0,0 point is located at the 2 μm peak.

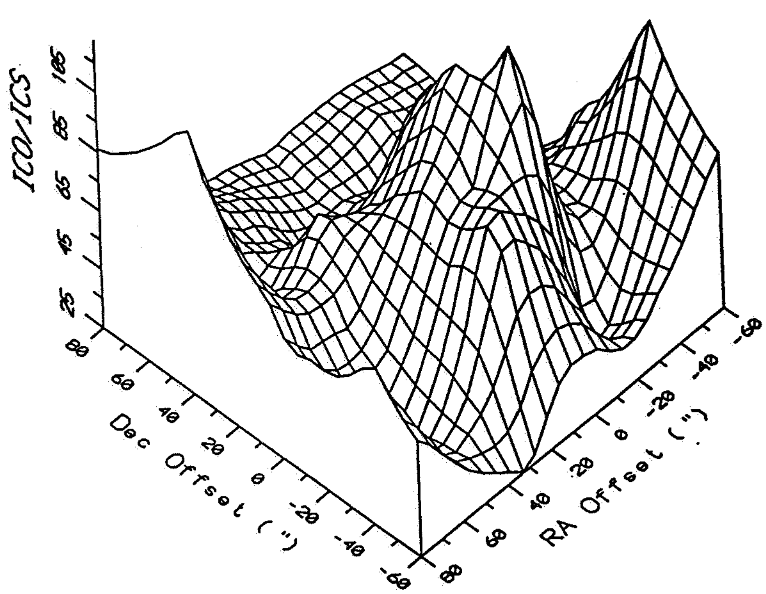

Figure 2 Surface plots showing the variation in the I_{CO}/I_{CS} ratio across M82.